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TRE MEMORANDUM NUMBER B5/M1/RA

ATI No. 1419 SECRET

## A BRIEF RESUME OF THE WORK DONE BY TRE ON "LONGSHOT

### 1. THE TYPE OF WEAPON

In its present form "Longshot" is envisaged as an air launched short range weapon. The Longshot dart is accelerated to a supersonic velocity by means of a rocket boost, and when the boost and dart have separated, the dart coasts and is automatically guided to the target aircraft flying along a beam laid down by a lock follow AI X-band Radar in the attacking aircraft. The Longshot dart will be controlled from a range of 1000' from the attacking aircraft and the expected range will be over 2000 yards.

The dart is roll stabilised and a proximity fuse will be used.

### 2. THE CONTROL SYSTEM

#### 2.1 Target Detection

Pulsed X-band Radars (e.g. Mark 9 AI X-band) at present designed or under design, can detect aircraft targets, which are within the forward looking hemisphere, and up to a range of 7 miles approximately. When the target range is less than 5 miles the radar is able to lock on to the target to within $1/4^{\circ}$, so that the position of the target aircraft relative to the attacking aircraft is known in range, azimuth and elevation. At maximum range, the error is of the order of 35 yards and at 2000 yards range the inaccuracy is of the order of 8 yards. This error is due to a variety of effects, which include:-

(i) imperfect lock follow.

(ii) a limitation in the sharpness of the aerial polar diagram.

(iii) the uncertainty of the position of the "centre of gravity" of the signal reflected from the target.

These effects result in a jitter in the measurement of the azimuth and elevation angles. However, if a pulsed X-band radar is used to lay down a beam to control the Longshot dart it is anticipated that satisfactory beam riding will be obtained.

#### 2.2 Missile Position Determination

For an automatically controlled missile flying along a beam laid down by a pulsed radar in the attacking aircraft to the target aircraft, certain information must be transmitted to the missile so that the position of the missile relative to the axis of the beam can be determined. The normal conical scan of the radar, locking on to the target aircraft, will provide at the missile a measure of the angular misalignment of the missile from the axis of the beam. This will appear as a sine wave amplitude modulation of the pulses as received at the missile.

Let f be the scanning frequency
Let $\theta$ be the misalignment angle of the missile to the beam axis
Let us measure the phase of the beam rotation from the time the beam is vertical
Let $\alpha$ be the phase of the misalignment sine wave relative to the phase of the conically scanning beam
Let R be the range of the missile from the radar
Let h be the linear misalignment of the missile from the beam
Let $h_V$ and $h_H$ be the components of the linear misalignment in the vertical and horizontal respectively

The misalignment sine wave has the form

$$\theta \sin (2\pi ft + \alpha)$$

/It

It is necesary to convert the angular misalignment $\theta$ to the linear misalignment h by using the relationship $h = R \sin \theta$; or for small angles $\theta$, $h = R\theta$. The range term is introduced in the missile by means of a clock operated potentiometer, and the linear misalignment sine wave becomes $h \sin (2\pi ft + \alpha)$.

It is assumed here that at the time the missile leaves the aircraft a gyro, which has been fixed relative to the aircraft, is released, and that the missile has been roll stabilised. The information on the position of the conical scan must be relayed to the missile. This is obtained by a pulse staggering technique. Alternate pulses are staggered from the equi-spaced position by an amount which is proportional to the sine of the angle of the beam rotation to the vertical.

Within the missile this pulse staggering is converted into a reference sine wave of large amplitude ($A \sin 2\pi ft$) and by means of a pair of phase sensitive rectifiers, the misalignment signal is split up into two components

$$h_V = h \cos \alpha$$

$$h_H = h \sin \alpha$$

In this way the position of the missile relative to the beam axis has been defined. The accuracy of the measurement of the position of the missile relative to the beam depends on the following factors:-

(i) the linearity of the modulation of the signal with the angle off the beam axis.

(ii) the linearity of the detector and amplifier in the missile receiver.

(iii) The accuracy of the phase sensitive rectifiers and the ability of the reference sine wave generator in the missile to cope with large amplitude changes of signal and spurious pulses.

## 2.3 Missile Control

The question of how the missile control surfaces should be moved in order to reduce the misalignment from the beam axis quickly and stably to zero must be considered in the light of the aerodynamics of the missile. The Longshot dart has crossed wings and crossed rudders behind the wings, and it is designed so as to have nearly neutral weathercock stability. The control of the dart is applied by moving the rudders from side to side. This causes the dart to yaw or pitch and lateral forces on the wings result.

In order to reduce the misalignment of the dart from the beam axis to zero the control circuit demands a lateral acceleration proportional to misalignment with some of the first differential of the misalignment fed in to give critical damping. The stiffness of this control is such that a misalignment of 15 feet with no lateral velocity demands 10 g acceleration sideways. Demands greater than this are limited to 10 g. The response time for a 150 foot step function of misalignment is about 2 seconds. To obtain a demanded lateral acceleration with rudders of the type described above a further loop is required since the equation connecting rudder position and lateral acceleration is itself a second order differential equation. A lateral accelerometer is therefore used as an intermediary in order to indicate when the required acceleration has been set up, and rudder reversals are demanded when the input demand is not exactly balanced out by the accelerometer output, the latter being phase advanced to give damping. Thus the missile flies with its rudders continually vibrating. This type of control is referred to as "bang-bang" control.

## 3. THE STATUS OF LONGSHOT

The block diagrams of the aircraft and missile equipments are given in the accompanying drawings in Fig. 1.

### 3.1 The Aircraft Equipment

The modifications to a standard lock follow AI X-band radar are indicated in the drawings. A series of 1/2 μsec. pulses of recurrence 1250 c/s are produced by the multivibrator. These pulses are fed to a phantastron circuit and a signal proportional to the sine of the angle of the beam rotation is also fed in. (A gyro unit will correct for the banking of the aircraft after the time of firing). From this phantastron circuit a series of pulses are produced which are staggered from the mid point of the equi-spaced pulses, and the two series of pulses are mixed and used to trigger the modulator.

### 3.2 The Missile Equipment

3.2.1 The aerial consists of an open-ended X-band wave guide set up at the tail of the dart. In order to ensure that the signal level at the crystal detector is constant an RF type of AGC is used. This AGC before the crystal must be used, so that the crystal will work at a constant point in its characteristic, and the law of detection will be independent of signal strength (and range). The RF AGC is obtained by a modified TR tube in which the keep alive current controls the attenuation of the signal. This attenuating characteristic has been obtained and the AGC has been illustrated. During the control period the dart and boost have separated and there is no interference due to rocket flame attenuation.

3.2.2 Video amplifiers have been made with satisfactory gain and distortion characteristics, but tests still have to be performed to clear up troubles due to microphonics. If these are unsuccessful, as revealed by bench and flight tests, consideration will be given to other forms of amplifiers.

3.2.3 At the present moment the circuit to produce the reference sine wave works satisfactorily if the misalignment is not too large and if there are no spurious interfering pulses. Changes in this circuit, at present under development should remove the above limitations. The phase sensitive rectifiers, which are used to combine the misalignment sine wave and the reference sine wave to give the two components of misalignment, make use of four rectifiers and work quite satisfactorily.

3.2.4 An outline of the working of the control circuit has been given above and a block diagram of the control circuit in one plane associated with an aerodynamic simulator is given in Fig. 2. A lateral acceleration proportional to misalignment (h) with some of the first differential of the misalignment ($a\,h'$) is demanded, and this is balanced against the measured lateral acceleration ($h''$) with some of the first differential of acceleration ($bh'''$). On account of the slow natural period of oscillation of the rudders, the AC component of a signal proportional to rudder position is also fed in to speed up the rudder oscillation. Using estimated aerodynamic constants in the aerodynamics simulator, stable and rapid responses of the system have been obtained. For example, with an initial misalignment (h) = 150', $h' = 0$ and $h'' = 0$, the misalignment

/is

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is reduced to zero in under 1.5 seconds and the overshoot is less than 15'.

3.2.5 Various methods of measuring the lateral acceleration have been used with varying degrees of success. A system which makes use of carbon piles has a very rapid response (1/200 sec.) but there are back-lash troubles. A mechanical accelerometer has been made but the natural period is too slow (1/16 sec.). The final accelerometer may take the form of a heavy mass constrained by a pair of springs to give a sufficiently rapid response. The movement would require mechanical amplification so that sweep of the arm of a potentiometer would be sufficient.

## 4. POSSIBLE FUTURE TRENDS

A decision has recently been made to change the mechanical form of the Longshot dart. RAE stated that the time to establish beam riding with the 3" diameter dart was not less than the time using a 5" diameter dart. The latter is a more probable size for the final weapon, and gives more space for experimental purposes when the dart is used as a test vehicle. Although this introduces a delay in the development of the radio components due to mechanical and aerodynamic changes, a greater freedom is given. This means that various schemes, which could not be used previously because of the space limitation, can now be tried. The following can now be investigated:-

4.1 Improved circuits for the generation in the dart of the reference sine wave.

4.2 Various methods of roll stabilisation and roll compensation.

4.2.1 A free gyro in the dart may be used to alter the phase of the reference sine wave, to resolve the linear misalignments into the planes of rudder control surfaces. In this case the dart is allowed to roll. The information on the orientation of the dart can be passed to the reference sine wave by means of a pair of sine/cosine potentiometers or by means of a magslip with a double rotor.

4.2.2 A polarisation method may be used. The 180° ambiguity can be removed by means of a relatively poor quality free gyro.

4.3 It may be possible to make use of an electromagnetic rudder servo. A bench model of a moving coil rudder servo has been shown to work satisfactorily although it is too large to fit in the 3" diameter dart.

4.4 It should be possible now to go to AC methods of measuring acceleration. Alternatively a valve accelerometer is contemplated. It may take the form of a double triode valve with the cathodes and anodes rigidly fixed and the pair of grids allowed to move under accelerating conditions. The changes in the two halves of the double triode can be used to measure acceleration. However, a critical damping of this valve accelerometer is difficult.

## 5. ELECTRONIC EXPERIMENTAL TOOLS USED IN THE LONGSHOT DESIGN AND TESTING

### 5.1 Simulators

The motion of the Longshot dart can be expressed by differential equations, involving various aerodynamical constants and variables. These differential equations can be solved by electronic means. In the control of Longshot there is the problem of bringing the dart rapidly and stably in to the beam axis. The determination of the constants in the control circuit is a simple operation using an electronic simulator.

/5.2

5.2 Roll Measurement

To assist in the design of the roll stabilisation unit (being made at RAE) a method of roll measurement has been designed. An oscillator feeding a dipole with its axis perpendicular to the dart axis, defines a reference plane in the missile. On the ground the signals are received using an aerial system with a plane of polarisation rotating at 50 c/s. The signal received will be sine wave modulated and the time interval between the zero of the sine wave and a vertical reference pulse is a measure of the rotational position of the missile. A continuously moving film method of recording will be used.

5.3 A Velocity Measuring Device

It is necessary to measure the dart velocity more accurately than the present method, i.e. a differentiation of the position co-ordinates measured by kinetheodolites. A CW system is being designed to measure the Doppler shift in frequency of the signal reflected from the missile. The frequency (or velocity) strobe locks on to the signal from the boost and dart combined. At the instant of separation, the strobe unlocks automatically and flies out to a high velocity, waits for a short time and then runs down until it locks on to the signal from the dart, because the dart is travelling faster than the boost. In this way a measure of the dart velocity is obtained before and after separation.

5.4 Telemetering

Work has been proceeding on the design of a pulse telemetering system for transmitting information from the Longshot dart to a ground station during flight. It will be possible to transmit back to the ground any five desired voltages, which may be DC or AC up to a frequency of about 50 c/s to represent various aerodynamical functions, or actual voltages in the radio control circuits of the dart.

RA/SP
3rd July, 1946
S. No. C684

# ELECTRONIC EQUIPMENT IN THE FIGHTER AIRCRAFT.

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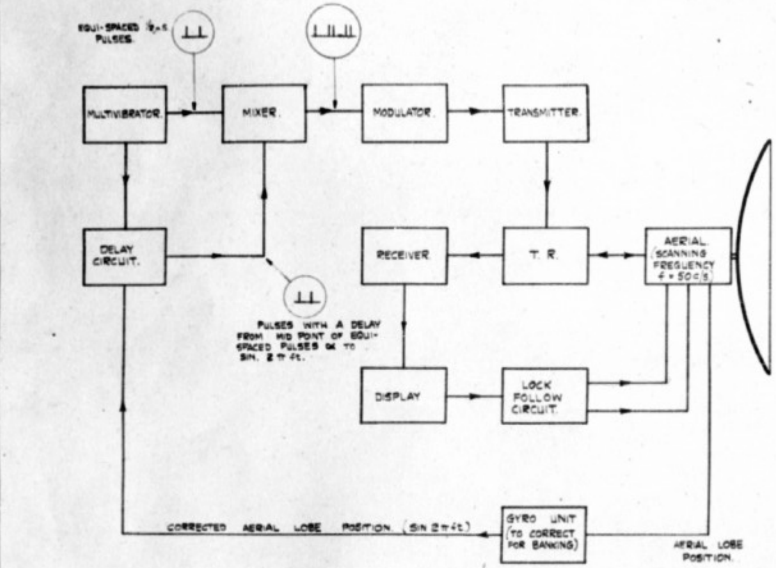
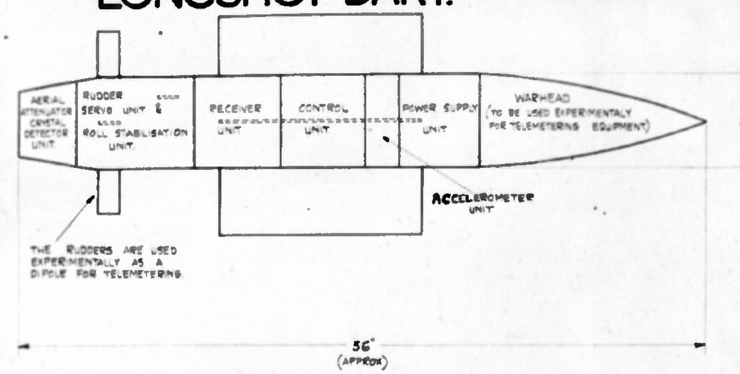
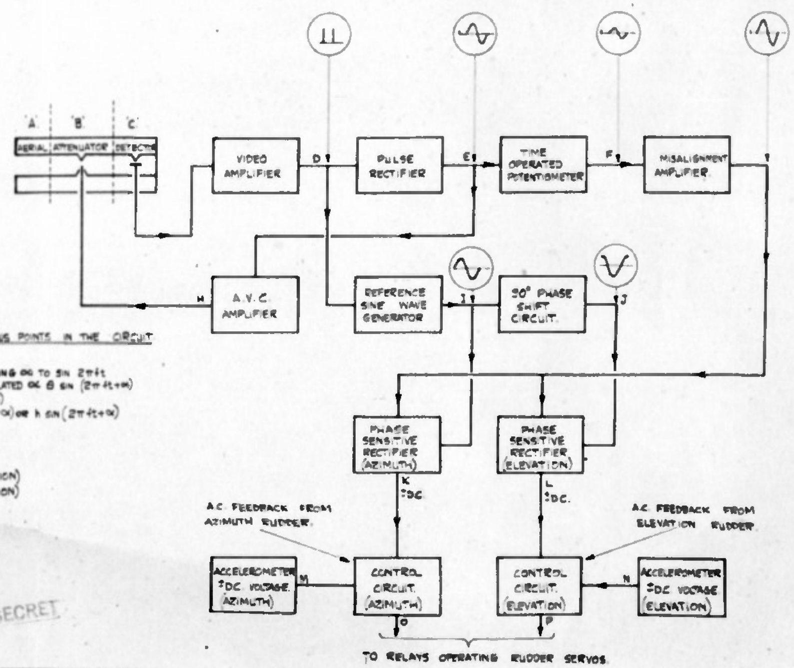
THE EQUIPMENT IS SIMILAR TO THE MK.9. A.I. (X BAND) WITH THE MODIFICATIONS AS INDICATED IN THE BLOCK DIAGRAM.




# ELECTRONIC EQUIPMENT IN THE LONGSHOT DART.




SIGNALS AT VARIOUS POINTS IN THE CIRCUIT

AT D. – ½µ-SEC. PULSES
– STAGGERED SPACING ∝ TO SIN 2πft
– AMPLITUDE MODULATED ∝ θ SIN (2πft + α)
AT E. – θ SIN (2πft + α)
AT F. – Rθ SIN (2πft + α) OR h SIN (2πft + α)
AT I. – A SIN 2πft
AT J. – A COS 2πft
AT K. – $h_h$ = h SIN α
AT L. – $h_v$ = h COS α
AT M. – $\ddot{h}_h$ (ACCELERATION)
AT N. – $\ddot{h}_v$ (ACCELERATION)

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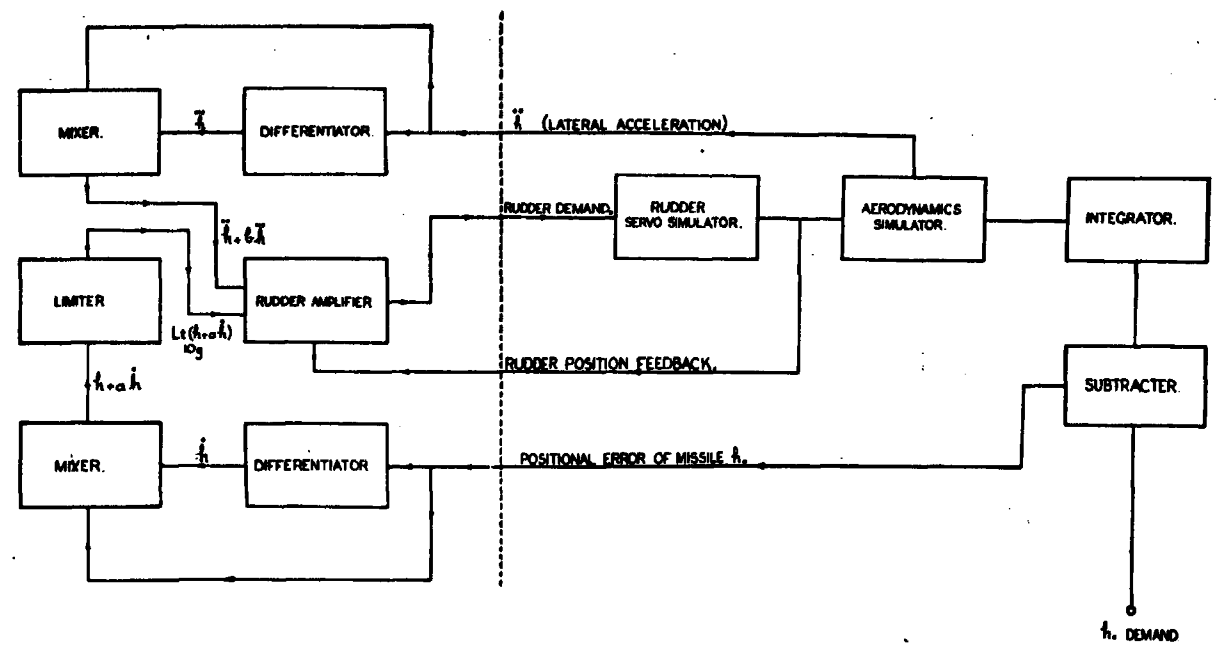
# LONGSHOT SIMULATOR IN 100:1 TIME SCALE.

## MISSILE CONTROL CIRCUIT.

## MISSILE SIMULATOR.



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ORIGINATING AGENCY: Telecommunications Research Establishment, Malvern
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